

The Influence of Nano Materials on Moisture Resistance of Asphalt Mixes

Amir Kavussi^{*1}, Peyman Barghabani²

Highway and Transportation Engineering, Faculty of Civil and Environmental Engineering, Tarbiat Modares University, Tehran, Iran

^{*1}kavussia@modares.ac.ir; ²p.barghabani@modares.ac.ir

Received 31 March 2014; Accepted 9 June 2014; Published 8 July 2014

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Abstract

Nano materials have been used in asphalt research projects in recent years in order to enhance rheological properties of bitumen and mechanical properties of asphalt mixes. The application of nano materials to asphalt mixes has been mainly limited to laboratory investigations due to excessive costs of these materials.

As moisture damage is one of the commonly occurring distresses in asphalt pavements, in this research, the effects of nano clay and nano hydrated lime were investigated on moisture susceptibility of a continuously graded asphalt mix. Moisture resistance of mixes were investigated, performing Indirect Tensile Strength (ITS) testing on mixes that contained various amounts of the above additives. Nano hydrated lime was produced in this research using a planetary ball mill. The average particle size of the produced nano hydrated lime was 281 nanometers. Results indicated that the addition of nano hydrated lime at 5% level (by weight of bitumen) and nano clay at 2% level, increased Tensile Strength Ratio (TSR) of asphalt mixes by 52 and 49%, respectively. It was also shown that the addition of hydrated lime in normal dosages (i.e. 20% by weight of bitumen) can be replaced by 5% nano hydrated lime in order to achieve mixes having maximum TSR values.

Keywords

Nano Hydrated Lime; Nano Clay; Moisture Damage; Indirect Tensile Strength

Introduction

Nano materials enhance properties of asphalt mixes in terms of reinforcing these against commonly occurring distresses, such as moisture damage, fatigue cracking and permanent deformation. Nano materials, having very high specific surface area, establish a strong network in bitumen and often lead to increased resilient modulus and rutting resistance of asphalt mixes (Ghile, 2006 and You et al., 2011). In addition, in

some research works, it was shown that the addition of nano materials to asphalt mixes increased their fatigue resistance appreciably (Khattak et al., 2012 and Liu et al., 2011).

The effects of nano materials, such as nano hydrated lime and Zycosoil, on moisture susceptibility of asphalt mixes, have recently been investigated (Moghadas Nejad et al., 2012 and Kavussi et al., 2014). Shen et al (2011) showed that nano hydrated lime, with average particle size of 600 nanometers, increased TSR of Hot Asphalt Mixes (HMA) by 8%. In another research, moisture susceptibility of WMA mixes, containing nano hydrated lime, was investigated (Cheng, Shen, and Xiao, 2011). This nano material had average particle size of 660 nanometers. These researchers concluded that TSR values of mixes containing nano hydrated lime were 10% greater than those in the control mix.

Moisture damage of asphalt mixes occurs within asphalt-aggregate system in a mix in presence of water. This is generally classified into two mechanisms of "loss of adhesion" and "loss of cohesion" (Kim, 2008 and Lottman, 2000). Loss of adhesion is due to water getting into the binder film that is coating the aggregate particles, stripping away the bitumen film. Loss of cohesion is mainly due to softening of filler-bitumen mastic that is present in the mix. Both of these could occur in the field during pavements service life, resulting in accelerated moisture damage on pavements (Epps et al., 2000).

Materials

Aggregates and Binder

A continuously graded aggregate was selected from a local source in Tehran in order to achieve maximum

interlock between aggregate particles. Grading of the selected aggregates is shown in Table 1 and their chemical compositions are listed in Table 2.

The binder used in all this research was a PG 58-22 bitumen with testing results reported in Table 3.

TABLE 1. GRADING OF THE SELECTED AGGREGATES

Sieve [mm]	Standard limits [%]	Passing [%]
19	100	100
12.5	90-100	95
4.75	44-74	59
2.36	28-58	43
0.3	5-21	13
0.075	2-10	6

TABLE 2. CHEMICAL COMPOSITION OF THE AGGREGATES

Properties	Percentage [%]
Silicon dioxide, SiO ₂	52.74
Aluminium oxide Al ₂ O ₃	10.98
Ferric oxide, Fe ₂ O ₃	3.47
Magnesium oxide, MgO	2.04
Calcium oxide, CaO	14.31
Potassium dioxide, K ₂ O	2.63
Sodium dioxide, Na ₂ O	1.98
Loss on ignition	10.94

Additives

In order to compare the effects of various additives on moisture resistance of the HMA mix, the following additives were used at different percentages:

- A mineral hydrated lime filler (passing 75 micron sieve size),
- Laboratory produced nano hydrated lime from the above filler (with average particle size of 281 nanometer), and;
- A nano clay (namely, Cloisite 30B).

Nano hydrated lime was produced in this research, applying a planetary ball mill at different time and rotating conditions (Figures 1 and 2). Nano clay was an organo montmorillonite that was modified with a quaternary ammonium salt. Properties of this latter material are reported in Table 4. The amounts of each of these additives (to be added to mixes) were selected based on visual observation of consistencies of the bitumen-additive mixtures at various amounts of the additives. Based on this criterion, asphalt mixes were prepared using hydrated lime and nano hydrated lime contents at 5, 10 and 20% by weight of bitumen. In the case of mixes containing nano clay, because of the very high surface area of this additive, this was added at the amounts of 2, 4 and 6% by weight of bitumen. The complete mixing conditions, including mixing time, rotation speed and the mixing temperatures are summarized in Table 5.

TABLE 3. PG TESTING RESULTS OF BITUMEN

Test	Temp. (°C)	Specification Limit	Measured Value
DSR @ High Temp. for Unaged sample	58	$G^*/\sin(\delta) > 1$ kPa	3.01
	64		0.962
DSR @ High Temp. for RTFO sample	58	$G^*/\sin(\delta) > 2.2$ kPa	3.619
	64		1.559
DSR @ Intermediate Temp. for PAV sample	13	$G^*.\sin(\delta) < 5000$ kPa	Fail
	16		Pass
BBR @ Low Temp. for PAV Sample	-12	Stiffness < 300 MPa m-value ≥ 0.3	100.2 MPa
			0.323
	-18		192.5 MPa 0.259

TABLE 4. PHYSICAL PROPERTIES OF NANO CLAY

Property	Result	
Base	Montmorillonite	
Organic modifier	MT2ETOH (Methyl, Tallow,Bis-2-Hydroxyethyl, Quaternary Ammonium)	
Moisture	Less than 2%	
Loose bulk	227 kg/m ³	
X-ray result	d ₀₀₁ =1.85 nm	
Particle sizes	Smaller than 2 μm	10%
	Smaller than 6 μm	50%
	Smaller than 13 μm	90%

TABLE 5. MIXING CONDITIONS OF BITUMEN AND ADDITIVES

Additive	Time (min)	Speed (rpm)	Temp. (°C)
Hydrated lime	20	3500	155
Nano hydrated lime	40	3500	160
Nano clay	30	5200	155



FIG. 1 PLANETARY BALL MILL

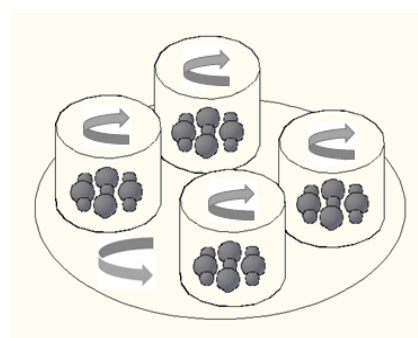


FIG. 2 SCHEMATICS OF THE PLANETARY BALL MILL

Indirect Tensile Strength (ITS) Testing

Indirect Tensile Strength (ITS) testing was performed on compacted samples that were kept at both dry and wet conditions. In accordance with AASHTO T-283 testing method, all samples contained 6.5 to 7.5% air voids. Six samples were prepared at each mix composition (i.e. three for dry and three for wet samples). Before testing, the saturated samples were subjected to freeze-thaw cycles. First, the vacuumed samples that were kept under wet conditions (at 70 to 80 percent levels) were placed at -18°C for 20 hours. After freezing, the samples were kept at 60°C under water for 24 hours. Indirect Tensile Test (ITT) was then performed at 25°C on all specimens. ITS and TSR values of the various samples were calculated using the following formulas:

$$ITS = \frac{2000P}{\pi tD} \quad (1)$$

$$TSR = \frac{ITS_{Sat}}{ITS_{Dry}} \quad (2)$$

Where, ITS is Indirect Tensile Strength (kPa),

ITS_{Sat} is ITS of the saturated samples subjected to freeze-thaw cycles,

ITS_{Dry} is ITS of the dry samples.

P is the failure load (N),

t is the sample thickness (mm) and,

D is the sample diameter (mm).

Results and Discussion

Laboratory Production of Nano Hydrated Lime

Nano hydrated lime was produced using a planetary ball mill (Figure 1). Parameters such as speed, time and Ball to Powder Ratio (BPR) were optimized using a trial and error procedure. The average particle size of nano hydrated lime was determined using SEM photos and Dynamic Light Scattering (DLS) graphs. During the milling process, average particle sizes of nano hydrated lime were measured at various time intervals, using Dynamic Light Scattering (DLS) device. The results are reported in Table 6.

SEM images of the processed samples indicated that the milling process had made the flat plates of hydrated lime particles to be transformed into spherical shape. The structure formed after 6 hours of milling (Figure 4) showed a higher specific area, compared with the initial structure shown in Figure 3. As it can be seen from Table 6, after 6 hours of milling,

the particle sizes of hydrated lime were increased appreciably. The reason for this was considered to be the coagulation of the particles. Tentative changes of the milling process showed that 6 hours of milling could be considered as the optimum timing to achieve finest particle size distribution of hydrated lime (i.e. 281 nm).

ITS Results

ITS and TSR testing results are reported in Figures 5 and 6. The addition of 2% nano clay and 5% nano hydrated lime resulted in increased TSR values of 49 and 53% respectively. This could be as a result of increased adhesion between bitumen and aggregate particles. Optimum amounts of hydrated lime and nano hydrated lime (for achieving maximum TSR values) were determined to be 20% for hydrated lime and 5% for nano hydrated lime. This indicates that with the case of nano hydrated lime, the optimized TSR values were achieved at lower percentages, compared with those in the ordinary hydrated lime filler.

TABLE 6. AVERAGE PARTICLE SIZE OF HYDRATED LIME AT VARIOUS MILLING PERIODS

Milling time (hour)	Average particle size (nm)
0	760
2	473
4	395
6	281
8	344
10	431

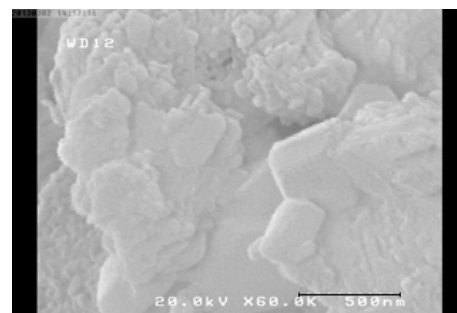


FIG. 3 SEM PHOTO OF HYDRATED LIME MINERAL FILLER

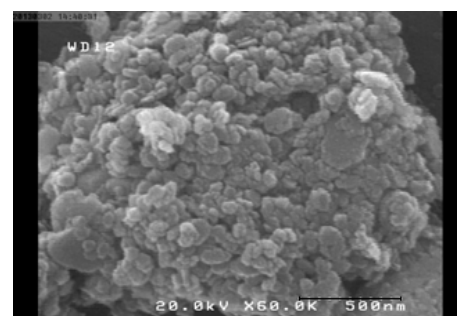


FIG. 4 SEM PHOTO OF NANO HYDRATED LIME AFTER SIX HOURS MILLING WITH PLANETARY BALL MILL

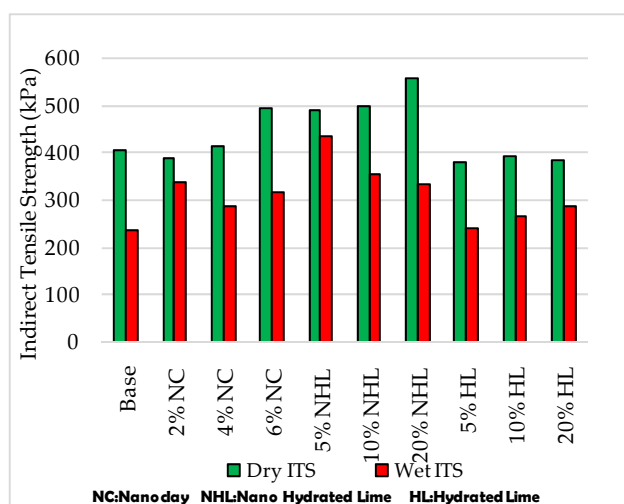


FIG. 5 INDIRECT TENSILE STRENGTH (ITS) TEST RESULTS

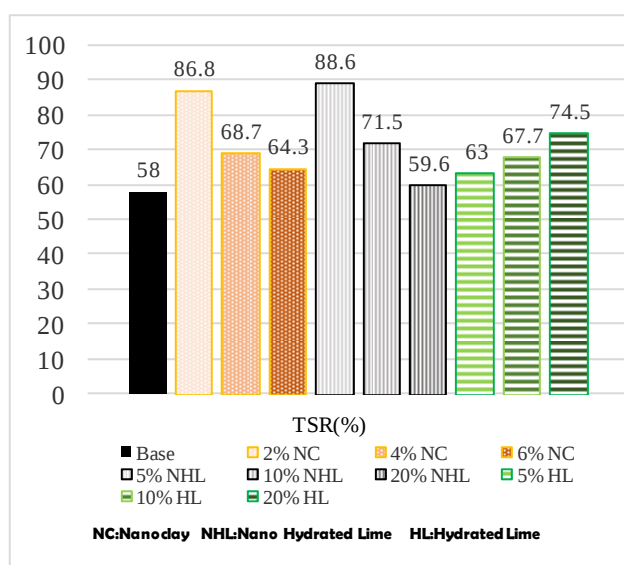


FIG. 6 TENSILE STRENGTH RATIO RESULTS OF MIXES CONTAINING ADDITIVES

Conclusions

Based on the results obtained from producing a nano hydrated lime additive in laboratory and performing Indirect Tensile Strength testing on mixes containing two nano materials and an active mineral filler, the following conclusions were drawn:

1. The addition of 5% nano hydrated lime to bitumen increased TSR values of asphalt mixes by 52%.
2. Using 2% nano clay in asphalt mixes resulted in 49% increase in TSR values.
3. Upon increasing Nano clay and Nano hydrated lime in mixes to greater levels, TSR values showed decreased and unacceptable levels.
4. With Nano hydrated lime, the optimized TSR values

were achieved at low percentages, compared with the case of the conventional hydrated lime filler. The reason for this was attributed to the increased surface area of this filler which was achieved after transforming that into a nano material.

5. In order to maximize moisture damage resistance of asphalt mixes, the addition of hydrated lime in normal dosages (20% by weight of bitumen) could be exchanged with 5% nano hydrated lime.

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